

ENERGY EFFICIENT COMPOSITES USING NATURAL ORGANIC MATERIALS

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Abstract: The increasing pace of human activities in the XX and XXI centuries led to a serious contamination of the planet by variety of production waste. Violation of the natural composition of air, quality of water, environmental degradation cause a number of irreversible pathophysiological changes in the human body, which justifies the need of cooperating activity of doctors hygienists and builders on creating an environmentally safe and comfortable human habitat. Evaluation of environmental costs and environmental gains from the use of thermal insulation materials made it possible to identify the environmental advantages of natural cheap heat insulators. The use of natural fibers, as well as waste from plant processing, as reinforcing elements of composite materials is one of the most important research tasks of modern materials research.

1 Introduction.

The economic activity of mankind over the past century has led to serious pollution of our planet with a variety of industrial waste. The air basin, water and soil in areas of large industrial centers often contain toxic substances, the concentration of which exceeds the maximum permissible level. According to scientists, up to 85% of human diseases can be associated with negative environmental conditions.

Global climate change, environmental pollution and the consequences of their impact on the environmental situation in the world necessitate the use of materials in technological processes that reduce the effects of these threats.

Energy efficiency, green technologies and sustainable construction and architecture mean protecting the environment, reducing the negative impact on nature, the careful use of natural resources, creating a more comfortable and healthy living environment for people, etc. Green standards are designed to accelerate the transition from the traditional design and construction of buildings and structures to a sustainable development strategy that preaches the following principles: safety and favorable healthy living conditions for people; limitation of negative environmental impact; taking into account the interests of future generations. One of the accepted definitions of sustainable development is "development that can meet the needs of the present and does not jeopardize the ability of future generations to satisfy their needs". Buildings are assessed in the following categories: design, construction and building management, the health and well-being of building users, energy use

(saving), transport accessibility, water use (saving), building materials, garbage processing, land use and ecology, environmental pollution. The strategic goal of the development of construction is the introduction of modern architectural and planning solutions based on the criteria of energy efficiency, resource efficiency and environmental safety.

In traditional construction, there are a number of aspects that can cause concern from the point of view of influence on the biosphere. One of these is the extraction of raw materials and, in fact, the production of building materials, the construction of energy-inefficient structures, the safety of materials during operation, the environmentally friendly disposal (the last part of the full life cycle).

Any material used in a modern typical building appears as a result of energy-intensive processing. Cement factories, metallurgical plants, woodworking and other enterprises of the construction industry, consume a huge amount of energy. At the end of the 20th century, American environmentalists calculated that more than a third of all raw materials used in the country are used in the construction of buildings, as a result, more than 30% of waste is generated in the form of construction waste, and taking into account operation, 36% of energy carriers, 65% of electricity are generated, 30% of greenhouse gases (in Europe about 40%), a large amount of drinking water is consumed. Thus, there is a wide potential for resource saving in this area, which has become one of the most important aspects (and the wording of the group of criteria) of the concept of green building construction and operation.

As a result of industrial activities, toxic waste is discharged into the water, and hazardous chemicals enter the air. The production of building materials (cement,

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wall materials, asbestos-cement products, building ceramics, heat – and soundproofing materials, building and technical glass, etc.), is accompanied by emissions of dust and suspended solids (over 55% of the total emission), carbon monoxide, sulfur dioxide, nitrogen oxides, etc. For example, when receiving upon varnishes, paints, artificial leather, into the environment with wastewater and atmospheric emissions of enterprises of basic organic synthesis into the atmosphere enters benzol with mutagenic, gonadotoxic, embryotoxic, teratogenic and allergenic effects [1]. In construction, a tendency toward the chemicalization of technological processes and the use of unsafe waste from the metallurgical and petrochemical industries as additives to building materials (concrete, brick, reinforced concrete, ceramics, varnishes, paints, etc.) are becoming increasingly apparent.

A modern person spends a large amount of his time indoors (in his house, in the office), and he has to experience the constant effects of substances released from building materials on his health. For example, formaldehyde, which has a general toxic effect (irritating, allergenic, mutagenic, sensitizing, carcinogenic), enters the air with the release of polymer building materials, insulation, chipboards, adhesives. The main amount of cadmium enters the environment in the production of non-ferrous metals, as well as cast iron, steel, cement; fuel combustion, as a result of weathering and erosion of plastic and metal-plastic products, paints, pigments and adhesive materials. This metal has a gonadotropic, embryotropic, mutagenic and nephrotoxic effect. This list can be continued for a long time, but the more dangerous is the total effect of the smallest particles of toxic substances from a variety of materials, which is practically impossible to calculate and cannot be regulated by any hygiene standards. At present, the safety of the artificial environment, a place where many people spend most of their lives, is becoming increasingly relevant. According to environmentalists, the home air of rooms with thermal insulation and decoration with some building materials is 4-6 times dirtier and 8-10 times more toxic than the outside.

Disposal of building materials is also associated with risks. Some materials can be recycled, but only a small part of them does not emit harmful products during recycling and does not require large economic costs. For example, construction debris generated after the demolition of old buildings is mostly non-toxic, but its significant volumes and the complexity of recycling are a big problem.

Thus, new requirements for materials that are produced for the construction industry, both in production technology and in application and disposal issues, are being put forward. Use of materials with low environmental impact throughout the life cycle of the building; reuse of materials; renewable resources; the closest possible location of factories of suppliers of building materials is an element of sustainable development. The most important result of the strategy is the preservation of public health (accelerating recovery, reducing the number of serious complications, reducing the cost of paying sick leave, increasing labor

productivity, etc.). Highly effective and safe thermal insulation is of particular importance within the framework of the concept of "an environmentally friendly home", since more than 40% of energy resources in the modern world are spent on heating and cooling buildings.

2 Classification of thermal insulation materials.

Thermal insulation of buildings is an important factor ensuring the thermal comfort of the user, especially at extreme temperatures in winter and summer. Thermal insulation reduces unwanted heat loss or excessive heating of air in the premises of buildings, and, accordingly, the cost of heating or air conditioning.

Proper thermal insulation of the building allows, in addition, to obtain additional benefits while reducing unwanted emissions into the atmosphere, mainly CO₂.

The construction of energy-efficient houses in combination with new sources of energy is the core of the energy policy enshrined in a series of European Union Directives, which encourage the maximum reduction of energy consumption in buildings as much as possible "as much as possible" (Directive 2012/27 / EU, Directive 2002 / 91 / EU, Directive 2006/32 / EU, Directive 2005/32 / EU) [2, 3].

In technical literature quite a lot of different classifications of heat-insulating materials are proposed (table 1).

Table 1. Classification of thermal insulation materials:

Indicator	Material Sample
Initial raw material	inorganic (fiberglass, mineral wool, asbestos-containing products; cellular glass, etc.) organic (ecowool, flax-edged plates, foams, etc.)
Structure	fibrous (mineral wool, glass wool); cellular (gas silicate, foam, foam concrete); granular (expanded clay, perlite, ash gravel)
Appearance and form	friable (cotton wool, perlite, etc.); flat (plates, mats, felt, etc.); shaped (cylinders, half cylinders, segments, etc.); string
Incombustibility	fireproof; flame retardant; combustible
Binder	containing a binder; not containing a binder

In his work T. Steidl proposed a new division of heat-insulating materials (table 2) into the following groups [4]:

- biodegradable materials, for example, materials consisting of flax and synthetic fibers, FLACHAUS, 2012;
- vacuum materials (vacuum insulated panel);
- insulating materials that absorb solar energy (solar type).

Table 2. Classification of heat-insulating materials according to [4]:

№	Classification	Material Sample
1.	Biodegradable materials	From flax fibers, fuel peat; Fiberboard; cement-bonded, magnesite plates; slabs of straw and reed; mats and felt made from flax and hemp; sheep wool mats and felt; ecowool
2.	Vacuum type materials	Filling of microsilica; polystyrene; from a combination of silicon dioxide, titanium oxide and carbon
3.	Heat-insulating materials that absorb solar energy	Three-chamber double-glazed windows with krypton filling; quartz airgel grains located between two sheets of glass; cellular or capillary structures with glass frames

P.J. Bjørn [5] proposed an alternative classification of heat-insulating materials (table 3). He believes that thermal insulation materials can be divided into three groups: traditional, state of art and prospective. Energy-efficient construction in practice involves the use of

Table 4. The most important technical characteristics of insulating materials:

Heat insulation material Indicator	Foam polystyrene XPS EN13164: 2008	EPS extruded polystyrene foam EN13163: 2008	Mineral wool EN13162: 2008	Polyurethane foam EN13165: 2008	Ecowool ETA-05/0186
Average density [kg/m ³]	28...32	14...19	100...170	30...60	32...65
Heat coefficient conductivity [W/ m ²]	0,030...0,040	0,031...0,042	0,036...0,045	0,023...0,035	0,040...0,043
Water absorption	After a long immersion - no more than 3%	No more than 5%	After a long full immersion no more than 3%	After a long full immersion no more than 5%	No more than 5%
Fire resistance	E	E	A1	E	B2

3 Life Cycle Assessment (LCA).

Life cycle assessment is the process of assessing the environmental impacts associated with a product, process or other action by determining and quantifying: the amount of energy consumed, material resources and emissions into the environment; quantitative and qualitative assessment of their environmental impact; identify and evaluate opportunities to improve the environmental status of the system.

natural building materials, which can be located near a construction site. This approach reduces environmental impacts and transportation costs [5].

Table 3. Classification of thermal insulation materials according to [5]:

№	Classification	Material Sample
1.	Traditional	mineral wool; expanded polystyrene (EPS); extruded polystyrene (XPS); cellulose; cork; polyurethane (PUR)
2.	State of art	Vacuum Insulation Panels (VIP); gas filled panels (GFP); aerogels; phase change materials (PCM)
3.	Prospective	Vacuum insulation panels (VIP); gas insulation materials (GIM); nano-insulating materials (NIM); dynamic insulation materials (DIM); NIM's Nano-particle Concrete (NanoCon)

At the same time, it should be emphasized that at present polystyrene and mineral wool are most widely used for thermal insulation. When choosing a heat-insulating material, the value of the coefficient of thermal conductivity is primarily taken into account. In addition, the insulation, like all other structural elements of the house, must be technologically advanced, durable and environmentally friendly. However, serious research on the ecology of building materials is not enough.

To assess the environmental impact of successive stages of the construction process, the so-called LCA (Life Cycle Assessment) analysis, developed in the 90s and presented in the works of several authors [6]. The LCA (Life Cycle Assessment) method in 1998 was formalized in ISO 14040-43 (GOST R ISO 14040). Instead of this document, ISO 14040 and ISO 14044 were deduced in 2006. The developed procedures allow calculating the mass values of parameters characterizing the environmental impact of the building process and

calculating the resulting Pt parameter (for example, Sima Pro 7.1, Ecoindicator 99).

The value P_t represents (10^3) the annual environmental burden per inhabitant of Europe. This value is calculated by dividing the total value of the environmental burden in Europe by the number of

inhabitants in Europe and then multiplying it by a scale factor of 1.0.

Tables 5 and 6 show the results of LCA analysis performed in paper [6] for the production and use of basic heat-insulating materials (per 1 m³ of material).

Table 5. LCA analysis of thermal insulation materials [6]:

Exposure categories	EPS (plate) [200 kg/m ³]	EPS (granules) [330 kg/m ³]	EPS [15 kg/m ³]	Mineral wool [120 kg/m ³]	PUR [45 kg/m ³]	Ecowool [60 kg/m ³]
Carcinogens	0,028	0,447	0,008	0,234	0,091	0,020
Emissions Organic	0,004	0,000	0,002	0,007	0,007	-0,01
Emissions Inorganic	1,034	1,629	0,639	1,564	4,155	-0,272
Climate change	0,604	0,473	0,166	0,773	0,743	-0,040
Radiation	0,006	0,001	0,000	0,016	0,004	0,000
Ozone Layer	0,000	0,000	0,000	0,001	0,000	0,000
Ecotoxicity	0,054	0,037	0,004	0,129	0,113	-0,016
Acidification/Eutrophication	0,191	0,193	0,113	0,509	0,478	-0,067
Land use	0,096	0,101	0,000	0,143	0,034	0,006
Minerals	0,018	0,006	0,000	0,010	0,053	-0,001
Fossil fuel	3,665	3,148	3,273	4,723	10,383	-0,460
Total	5,699	6,035	4,205	8,108	16,062	-0,832

Table 6. The results of LCA analysis of thermal insulation materials [6]:

Hazard categories	EPS (plate)	EPS (granules)	EPS	Mineral wool	PUR	Ecowool
Human health	1,676	2,551	0,815	2,594	5,001	-0,292
Ecosystem quality	0,340	0,329	0,117	0,782	0,625	-0,078
Raw materials	3,683	3,154	3,273	4,733	10,436	-0,461
Total	5,699	6,035	4,205	8,108	16,062	-0,832

As can be seen from the results presented in tables 5, 6, the greatest environmental impact among the analyzed heat-insulating materials is exerted by polyurethane foam (16,062Pt). This is approximately two times more than in the production of mineral wool plates. Such indicators are characteristic of all polymer insulation materials in construction, and these are mainly foam plastics – dispersed polymer systems. These are organic compounds with a high contact surface with a gas medium, which, regardless of the initial composition of the polymer composition, inevitably is replaced by air over time. This is due to the fact that upon contact of the organic compound with air, it will be oxidized by oxygen, and oxidation products can be toxic. All foams have negative operational features: the destruction of the material for a short time under the influence of atmospheric oxygen even at a normal temperature [9], an excess of the concentration of toxic substances, fire hazard, the content of toxic organic compounds in the smoke during a fire, short life (significantly lower than the building's service life). The main disadvantage of all types of polystyrene foam is its poor knowledge of it as a building material. Properties of expanded polystyrene, including negative, come from its nature as a polymer. The stability of its thermophysical characteristics over time largely depends on the manufacturing technology and compatibility with other building materials in the

construction of walls and coatings. Expanded polystyrene releases benzol and toluene as a result of natural destruction. We can not ignore the effects of a number of random operational factors that accelerate the natural process of destruction of expanded polystyrene. In addition, the behavior of expanded polystyrene during a fire significantly distinguishes it from other heat-insulating materials. It is a combustible material that has high toxicity and smoke generating ability. Such properties as fire hazard, fragility, environmental hazard of polystyrene foam require additional research. Similar conclusions can be made by considering other types of polymer insulation. Polyurethane foam, widely used for thermal insulation, incorporates prepolymers, soft polyurethane resins, isocyanate hardeners, which are dangerous for humans (cause allergic reactions and severe forms of respiratory system diseases), and in the event of fire contribute to the formation of toxic combustion products.

In the manufacture of rigid and semi-rigid fiber products, the mineral fiber is impregnated with a sprayed synthetic binder. The nature of the distribution of the polymer in such an article suggests its high specific surface area. This reduces durability, creates the danger of toxic emissions into the environment, especially during fires. As for environmental problems not related to the polymer bond, but concerning the actual mineral

fibers, there is currently no definite answer to the danger of the influence of fibers, especially superthin. Inorganic fibers over time crumble into shorter lengths – microparticles that settle in the lungs and lead to the formation of diseases (dermatoses, obstructive bronchitis, bronchial asthma, etc.).

The negative value of the indicator for natural materials designated as ecofiber shows the environmental benefits already at the manufacturing stage. This is due to the use of natural renewable materials (cellulose, flax, hemp, etc.).

4 Energy efficient natural organic composites.

The directions of modern research and the practical application of such composites is defined as the “green approach” and is associated with the transition from the use of limited in stocks and non-renewable materials to easily renewable natural materials of plant origin.

The use of natural fibers, as well as waste from plant processing, as reinforcing elements of composite materials, is one of the most important research tasks of modern materials science research [6, 7, 8].

One of the elements ensuring sustainable development is the rational use of agricultural waste. The flax boon remaining after its processing can be considered in this context as a rather effective organic material that improves the properties of building composites.

Insulating materials made from flax fiber are represented by a wide range of products (table 7). Their advantages lie in the fact that they receive such materials from renewable sources and they have an inherent ability to biological decomposition. For example, in one of the suggestions [6] the insulating material contains 80% flax fiber, 10% potato starch and 10% fire retardant (sodium octaborat). Flax fiber products are classified as fire resistant according to EN 13501-1. Such materials make it possible to regulate the humidity in the premises quite well and, as one of the main advantages, are easily processed. Typically, the thermal conductivity coefficient is $\lambda=0,038 \text{ W/m}^2$ при плотности 30...50 kg/m³.

Table 7. The use of fillers of plant origin for heat/sound insulation:

<i>Agricultural waste</i>	
Filler	Application
Cereal straw	Pressed blocks, mats for walls, slabs of chopped straw on an inorganic binder (liquid glass), aggregates for wood concrete, peat blocks (geocar)
Flax boon	Piled-up boon is used for warming of floors and attics; boon plates on synthetic binders, liquid glass and styrene-butadiene latex, bitumen emulsion, fillers for arbolite, peat blocks (geocars), composite plywood, composite chipboards,

	non-binder boards; boon concrete (slabs, blocks)
Sunflower husk	Plates with urea-formaldehyde binder
<i>Отходы растительного происхождения</i>	
Reed	Swire stitched plates
Bulrush	Pressed plates, bulrush fiber plates, slabs of bulrush waste with synthetic resins, mats, bulrush concrete (blocks, plates)

5 Assessment of ecological costs and ecological profit from using thermal insulation materials.

Environmental costs (ecological costs) of conventional thermal insulation for exterior walls (per 1 m²) are determined according to the formula [6]:

$$K_s = d \cdot K_t (P_t / m^2), \quad (1)$$

where K_t – the result of calculating LCA per 1 m³ of thermal insulation material (P_t / m^3);

d – the thickness of the layer of thermal insulation material, m.

Ecological benefits (ecological benefits) during the period of use (operation) of the building as a result of the application of heat-insulating material according to [6] are calculated by the formula [6]:

$$Z_s = (E_{U0} - E_U) \cdot n / P, \quad (2)$$

where E_{U0} – the LCA calculation result for one year of operation of the building, in which the outer wall has a heat transfer coefficient U_0 (without outer heat insulation), P_t / year;

E_U – LCA calculation result for one year of operation of the building, in which the outer wall has a heat transfer coefficient U taking into account thermal insulation, P_t / year;

n – a building service life;

P – the surface area of the exterior walls of the building.

The value E_U (as well as E_{U0}) is determined by the formula:

$$E_U = D_E \cdot K_e (P_t / \text{год}), \quad (3)$$

where D_E – the heat demand for the entire building (kW / year);

K_e – the LCA calculation result to obtain 1 kW of thermal energy for conventional energy sources (P_t / kW).

As a rule, special programmes are used to calculate D_E over the service life (for example, Herz OZC [10]).

6 Conclusion.

The construction of energy-efficient houses in combination with new energy sources allows to significantly reduce energy consumption in buildings and thereby reduce the effects of these threats. One of

the elements ensuring a sustainable development is the rational use of agricultural waste. The use of natural building materials, which may be located close to the construction site, reduces adverse environmental effects. The use of natural fibers, as well as waste from plant processing, as reinforcing elements of composite materials, is one of the most important research tasks of modern material science research. The evaluation of environmental costs and environmental benefits from using thermal insulation materials has allowed to reveal the environmental benefits of low-cost natural thermal insulators.

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